Considerando il processore MIPS64 e l’architettura descritta in seguito:

|  |  |  |
| --- | --- | --- |
| * + Integer ALU: 1 clock cycle   + Data memory: 1 clock cycle   + FP multiplier unit: pipelined 8 stages | * + FP arithmetic unit: pipelined 4 stages   + FP divider unit: not pipelined unit that requires 10 clock cycles   + branch delay slot: 1 clock cycle, and the branch delay slot disabled | * + forwarding enabled   + it is possible to complete instruction EXE stage in an out-of-order fashion. |

Usando il frammento di codice riportato, si calcoli il tempo di esecuzione dell’intero programma in colpi di clock e si completi la seguente tabella.

; for (i = 0; i < 100; i++) {

; v5[i] = v1[i]/v2[i];

; v6[i] = (v1[i]\*v2[i])+(v3[i]/v4[i]);

;}

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| .data |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | Clock  cycles |
| V1: .double “100 values” |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| V2: .double “100 values” |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| V3: .double “100 values”  …  V5: .double “100 zeros” |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| V4: .double “100 values” |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| V5: .double “100 values” |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| V6: .double “100 values” |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| .text |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| main: daddui r1,r0,0 | f | d | e | m | W |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 5 |
| daddui r2,r0,100 |  | f | d | e | m | W |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |
| loop: l.d f1,v1(r1) |  |  | f | d | e | m | W |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |
| l.d f2,v2(r1) |  |  |  | f | d | e | m | W |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |
| l.d f3,v3(r1) |  |  |  |  | f | d | e | m | W |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |
| l.d f4,v4(r1) |  |  |  |  |  | f | d | e | M | W |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |
| div.d f5,f1,f2 |  |  |  |  |  |  | f | d | / | / | / | / | / | / | / | / | / | / | m | w |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 10 |
| s.d f5,v5(r1) |  |  |  |  |  |  |  | f | d | e | s | s | s | s | s | s | s | s | s | m | W |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |
| mul.d f5,f1,f2 |  |  |  |  |  |  |  |  | f | d | s | s | s | s | s | s | s | s | \* | \* | \* | \* | \* | \* | \* | \* | m | w |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| div.d f6,f3,f4 |  |  |  |  |  |  |  |  |  | f | d | s | s | s | s | s | s | s | / | / | / | / | / | / | / | / | / | / | m | W |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| add.d f1,f5,f6 |  |  |  |  |  |  |  |  |  |  | f | d | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | + | + | + | + | m | W |  |  |  |  |  |  |  |  |  |  |
| s.d f1,v6(r1) |  |  |  |  |  |  |  |  |  |  |  | f | d | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | m | W |  |  |  |  |  |  |  |  |  |
| daddui r1,r1,8 |  |  |  |  |  |  |  |  |  |  |  |  | f | d | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | e | m | W |  |  |  |  |  |  |  |  |
| daddi r2,r2,-1 |  |  |  |  |  |  |  |  |  |  |  |  |  | f | d | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | m | W |  |  |  |  |  |  |  |
| bnez r2,loop |  |  |  |  |  |  |  |  |  |  |  |  |  |  | f | d | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | m | W |  |  |  |  |  |  |
| halt |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Total |  |  |  |  |  | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  |

Please consider an optimization of 3CC for the DIV: 7CC instead of 10CC to execute.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| .data |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | Clock  cycles |
| V1: .double “100 values” |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| V2: .double “100 values” |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| V3: .double “100 values”  …  V5: .double “100 zeros” |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| V4: .double “100 values” |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| V5: .double “100 values” |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| V6: .double “100 values” |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| .text |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| main: daddui r1,r0,0 | f | d | e | m | W |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| daddui r2,r0,100 |  | f | d | e | m | W |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| loop: l.d f1,v1(r1) |  |  | f | d | e | m | W |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| l.d f2,v2(r1) |  |  |  | f | d | e | m | W |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| l.d f3,v3(r1) |  |  |  |  | f | d | e | m | W |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| l.d f4,v4(r1) |  |  |  |  |  | f | d | e | m | W |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| div.d f5,f1,f2 |  |  |  |  |  |  | f | D | e | e | e | e | e | e | e | m | W |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| s.d f5,v5(r1) |  |  |  |  |  |  |  | f | d | E | s | s | s | s | s | s | m | W |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| mul.d f5,f1,f2 |  |  |  |  |  |  |  |  | f | d | s | s | s | s | s | s | e | e | e | e | e | e | e | e | m | w |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| div.d f6,f3,f4 |  |  |  |  |  |  |  |  |  | f | s | s | s | s | s | s | d | e | e | e | e | e | e | e | s | m | W |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| add.d f1,f5,f6 |  |  |  |  |  |  |  |  |  |  | F | s | s | s | s | s | s | d | s | s | s | s | s | s | s | e | e | e | e | m | w |  |  |  |  |  |  |  |  |  |  |  |  |  |
| s.d f1,v6(r1) |  |  |  |  |  |  |  |  |  |  |  | f | s | s | s | s | s | s | s | s | s | s | s | s | s | d | e | s | s | s | m | W |  |  |  |  |  |  |  |  |  |  |  |  |
| daddui r1,r1,8 |  |  |  |  |  |  |  |  |  |  |  |  | f | s | s | s | s | s | s | s | s | s | s | s | s | s | d | s | s | s | e | m | w |  |  |  |  |  |  |  |  |  |  |  |
| daddi r2,r2,-1 |  |  |  |  |  |  |  |  |  |  |  |  |  | f | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | s | d | e | m | W |  |  |  |  |  |  |  |  |  |  |
| bnez r2,loop |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | s | s | s | s | s | s | s | d | e | s | s | m | W |  |  |  |  |  |  |  |  |  |  |  |  |  |
| halt |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Total |  |  |  |  |  | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  |

Solution by observation: speedup =

Solution by computation: speedup\_div = fraction = speedup = 1/((1-fraction)+fraction/speedup\_div)

**Domanda 2**

Considerando il programma precedente e l’architettura del processore superscalare descritto in seguito; completare la tabella relativa alle prime 2 iterazioni.

Processor architecture:

* + Issue 2 instructions per clock cycle
  + jump instructions require 1 issue
  + handle 2 instructions commit per clock cycle
  + timing facts for the following separate functional units:
    1. 1 Memory address 1 clock cycle
    2. 1 Integer ALU 1 clock cycle
    3. 1 Jump unit 1 clock cycle
    4. 1 FP multiplier unit, which is pipelined: 8 stages
    5. 1 FP divider unit, which is not pipelined: 10 clock cycles
    6. 1 FP Arithmetic unit, which is pipelined: 4 stages
  + Branch prediction is always correct
  + There are no cache misses
  + There are 2 CDB (Common Data Bus).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| # iteration |  | Issue | EXE | MEM | CDB x2 | COMMIT x2 |
| 1 | l.d f1,v1(r1) | 1 | 2 | 3 | 4 | 5 |
| 1 | l.d f2,v2(r1) | 1 | 3 | 4 | 5 | 6 |
| 1 | l.d f3,v3(r1) | 2 | 4 | 5 | 6 | 7 |
| 1 | l.d f4,v4(r1) | 2 | 5 | 6 | 7 | 8 |
| 1 | div.d f5,f1,f2 | 3 | 6/ |  | 16 | 17 |
| 1 | s.d f5,v5(r1) | 3 | 6 |  |  | 17 |
| 1 | mul.d f5,f1,f2 | 4 | 6\* |  | 14 | 18 |
| 1 | div.d f6,f3,f4 | 4 | 16 / |  | 26 | 27 |
| 1 | add.d f1,f5,f6 | 5 | 27+ |  | 31 | 32 |
| 1 | s.d f1,v6(r1) | 5 | 7 |  |  | 32 |
| 1 | daddui r1,r1,8 | 6 | 7i |  | 8 | 33 |
| 1 | daddi r2,r2,-1 | 6 | 8i |  | 9 | 33 |
| 1 | bnez r2,loop | 7 | 10 |  |  | 34 |
| 2 | l.d f1,v1(r1) | 8 | 9 | 10 | 11 | 34 |
| 2 | l.d f2,v2(r1) | 8 | 10 | 11 | 12 | 35 |
| 2 | l.d f3,v3(r1) | 9 | 11 | 12 | 13 | 35 |
| 2 | l.d f4,v4(r1) | 9 | 12 | 13 | 14 | 36 |
| 2 | div.d f5,f1,f2 | 10 | 26 |  | 36 | 37 |
| 2 | s.d f5,v5(r1) | 10 | 13 |  |  | 37 |
| 2 | mul.d f5,f1,f2 | 11 | 13 |  | 21 | 38 |
| 2 | div.d f6,f3,f4 | 11 | 36 |  | 46 | 47 |
| 2 | add.d f1,f5,f6 | 12 | 47 |  | 51 | 52 |
| 2 | s.d f1,v6(r1) | 12 | 14 |  |  | 52 |
| 2 | daddui r1,r1,8 | 13 | 14 |  | 15 | 53 |
| 2 | daddi r2,r2,-1 | 1 | 15 |  | 16 | 53 |
| 2 | bnez r2,loop | 14 | 17 |  |  | 54 |